Surface Engineering for Corrosion and Wear Resistance Application
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Lecture – 22
Shot Peening

So, welcome to the 22nd lecture of Surface Engineering. We will having first defined what is surface engineering and but even before that we started talking about a various classification of engineering solids, the evolution of microstructure, the various defects associated with solids. And we classified various kinds of surface engineering techniques, but before that we also classify different surface dependent properties of the physical chemical and structural properties of mechanical properties.

And then we discuss at length about each of these properties separately, but now is the time when we actually should discuss specific surface engineering techniques. To begin with we may broadly classify the entire gamut of surface engineering into two major groups the conventional surface engineering which are very age old practices, very well established.

And many of them are still very widely practiced because they are economical and they are easy to implement and they have a large utility in various manufacturing practices. We also will discuss some of the advanced surface engineering techniques which could be essentially thin film based or using direct energy beams and so on.

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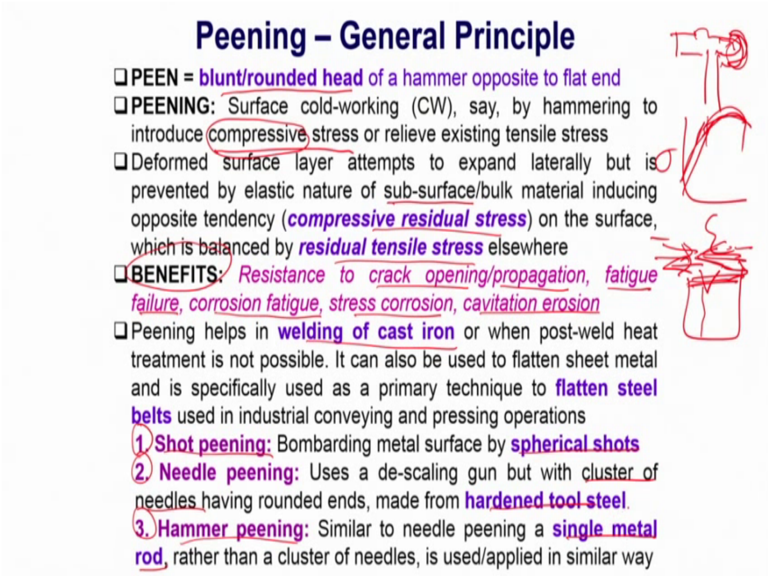

So, to begin with the conventional practices the very first technique we are going to discuss today is called shot peening or peening for that matter. In fact, if you just you know think of an hammer. So, if this is the hammer one portion of the hammer will have a flat head and the other portion will have a round head. So, this rounded portion is called the pin.

So, the blunted or the rounded head of the hammer is called the peen and when you hit any flat surface with this kind of a rounded head so; obviously, its going to create certain deformation and that will be a diffuse deformation. When you deform then you create a deformation zone underneath and that particular zone if its a metallic material is likely to create certain higher density of dislocations and also because of the recovery process there will be residual stress developed which is compressive in nature.

So, this is the principle theme of shot peening that you apply limited surface deformation and the material deforms only up to a very limited depth, but during the process of recovery certain amount of state of stress is created which is residual in nature. That means, when you remove the load still that particular stress remains and that stress incidentally is of compressive nature which is beneficial for very many like mechanical applications or applications which actually subjected to various mechanical deformation.

So, when we actually try to deform there could be there, there is always if you look at this typical stress strain diagram, there will be initially an elastic region proportional and then followed by a plastic deformation region. So, we are essentially talking about this region which is beyond the yield stress, but this deformation zone as I said is very limited from the surface.

So, if this is the bulk we are talking about just I mean weigh less than millimeter may be of only a few micro meter depth of deformed layer. So, this deform layer is limited to what is known as subsurface region the bulk may actually a develop residual tensile stress, but the surface will develop residual compressive stress.

So, what are the benefits, why do we intend to do that? These kind of residual state of stress which is compressive in nature are actually is an useful. So, that because it provides a resistance to crack opening or propagation it improves the fatigue life or reduces fatigue failure it creates resistance to corrosion fatigue , stress corrosion or cavitation erosion.

So, all these surface damages are reduced minimized or in some cases even prevented if we can create such a state of stress which is compressive in nature. In certain manufacturing operations for example, welding and that to welding of caster and there is no post weld treatment possible and we all know that in any fusion welding process of fusion joining process when the lipid solidifies the state of stress on the surface is tensile in nature which is not very conducive for creating or inducing greater fatigue strength,

In other words if there is a crack on to the surface under residual tensile stress, the crack can easily open. So, if you have a crack here and if you have a residual tensile stress then; obviously, this crack can very easily opened and we do not want this to happen. So, we would always prefer to have a situation where the state of stress is working towards each other or compressive in nature. So, for a welded zone particularly at the root of the welded zone if we can create such residual compressive stress by way of hitting with ultra fine spherical balls then that is beneficial, it can be done on a flat surface.

It can be done even on curved or surfaces with complex geometry. So, there are three possible ways of a introducing such residual compressive stress onto the surface. Typically the shot peening where we use spherical shots needle pinning where actually you when you use a cluster of needles very fine ultrafine needles and made from hardened steel or we can do hammer peening. So, this can be a single metal rod hitting onto the surface and so, this is wider. So, this is the finest and this also could be fairly fine, but this is the widest or the wider level of deformation done on to the surface.

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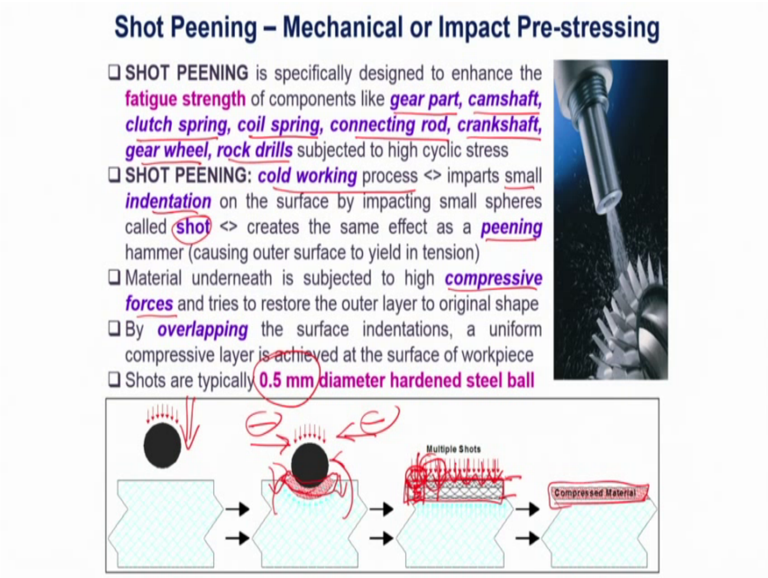

Now, for shot peening using this impacting spherical shots we actually can enhance the fatigue strength as I mentioned. On typical engineering components like gear parts the camshaft, clutch spring, coil spring, connecting rods crank shafts all kinds of rotating members raw rock drills and so on where fatigue is a standard way of failure.

And if we can create a residual compressive stress on to the surface then we defer we actually in some cases even prevent such crack growth or fatigue failure. So, its a cold working process; obviously, because we most of these are done at room temperature or certainly way below the crystallization temperature.

So, the deformation zone or the deformation effects are retained onto the sample it imparts small indentation just like when we use hard for hardness testing when we press a hardened steel ball onto the surface we create an indentation. In the same way, but the spherical objects that we are thrown in our ultrafine very small so, the inundation size is very very small. And this indentation is done by so called spherical objects called shots and the effect is called peening just bit like it is very similar to the peening with a hammer. So, the forces that actually we apply for individual impact is a actually compressive in nature.

So, there is a very small deformation zone and so, initially let us say this is the object which is propelled on to the surface at some very high velocity. So, when it impacts to the surface we create certain deformation zone like here and as we create deformation zone we try to push the material downwards and the reaction to that will be such that the material will try to come back and when it tries to come back the state of stress, that we create onto the surface is compressive in nature. So, we create residual compressive stress onto the surface. Now this is for a single impact.

If we have multiple impacts of very small sized balls we are talking about 0.5 millimeter. So, a fairly small 500 micrometer and when we have multiple such impact events occurring on to the surface so, they are all essentially incident onto the surface. And when the when the first impact occurs the second one actually need not come simultaneously at the same spot, but the second one comes after time lag and when it falls in another portion there will be some overlap, overlap of plastic region. So, if this is the plastic zone created by the first impact the second impact which will have certain overlapping region will have this amount of overlapping zone.

So, in the process the deformation that we create onto the surface will have more or less uniform depth, but also will have fairly homogeneous deformation structure on to the surface. So, we end up getting a region onto the surface which will carry a compressive state of stress.

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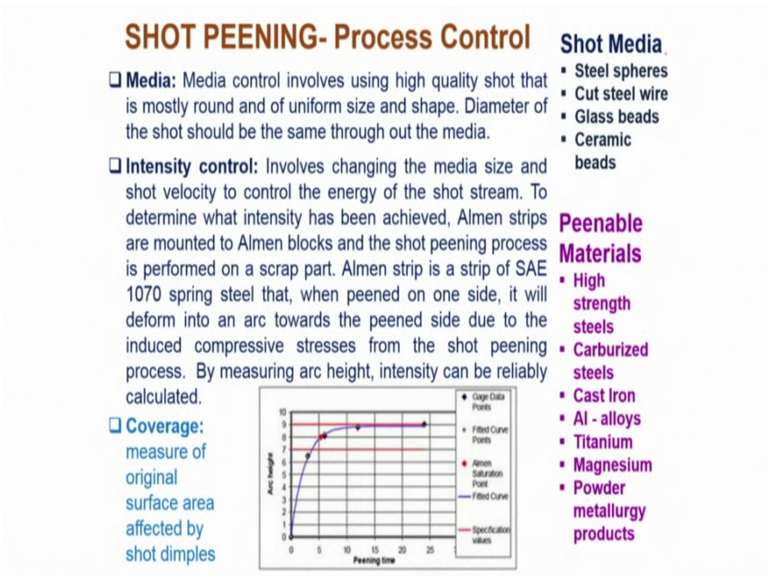

Now, what are the various media that we can use for such impact making? We can use spheres made of hardened steel we can use cut wires of steels of high aspect ratio, we can use glass beads which are very high in plastic modulus we can even use ceramic beads which can have even higher modulus. So, these are non deformable substances very high hardness and most importantly rigid and they do not deform.

In fact, they do deform and if they deform substantially then we need to change the set of shots that we are using for short PD. The diameter usually is very similar or the same throughout the media. Now we control the intensity by applying certain empirical relationships, which is created through by using so, called the element strip.

So, essentially you actually have a steel strip on to the surface and then by way of hitting these hitting by these shots the strip actually bends towards the impacting side and by looking at the angle of bending, we actually can make an educated get guess about the amount of compressive stress that we are creating. And accordingly we can actually manipulate the velocity and hence the momentum with which these shots are impacting the surface.

So, when we actually allow such shots to hit the surface at a very high speed we actually can make use of this kind of a calibration using the element strip to control the speed and control the level of stress that we can generate onto the surface.

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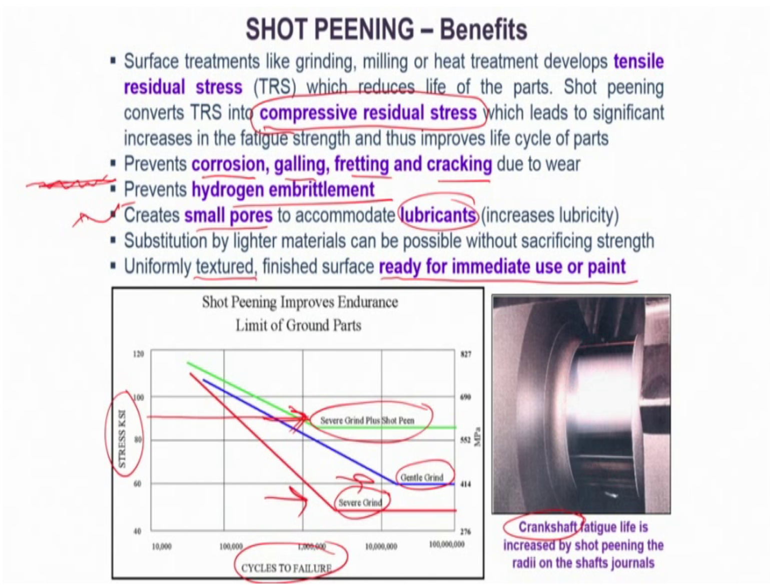

So, there are many very many advantages of using shot such an action. So, the first and foremost thing or the principle thing is that we are able to create such residual compressive stress onto the surface. And this goes on to prevent various types of corrosion, galling fretting or cracking type of a wire wear or abrasion it can minimize or prevent hydrogen embrittlement. It also creates certain very small dents instead of pores I would rather call them dents and these dents actually could it so.

On the surface you create such little bit of waviness the depth of which could be much less than tense of a micrometer maybe a few micrometers, but these dents actually are good. So, because they can reserve some amount of a or contain some amount of lubricants which actually are useful for subsequent motion between the surfaces. Usually by way of this deformation we actually create certain deformation texture and but the finished surface can easily be subjected to final finish or painting. Now the benefit was the biggest benefit for example, here we are describing the number of cycles and.

So, essentially the state of stress or the maximum stress required for failure for a given number of cycles. So, the maximum number of cycles required for failure. So, this we know typically is the so, called endurance limit and when we have the same material subjected to severe grinding operations, gentle grinding operations and severe grinding followed by shot peening operation what we see is that at any given number of cycles the endurance limit is always highest.

So, the maximum endurance is created when we follow grinding with shot peening. So, this kind of shot peening operation for example is very useful on all rotating parts I already mentioned and such kind of a big crankshaft. We can introduce now because of this large size you cannot do any operations easily on this kind of a component, but you can bring in a gun and you can do shot peening on this kind of a surface curved surface and create residual compressive stress and that is how you can improve the fatigue strength.

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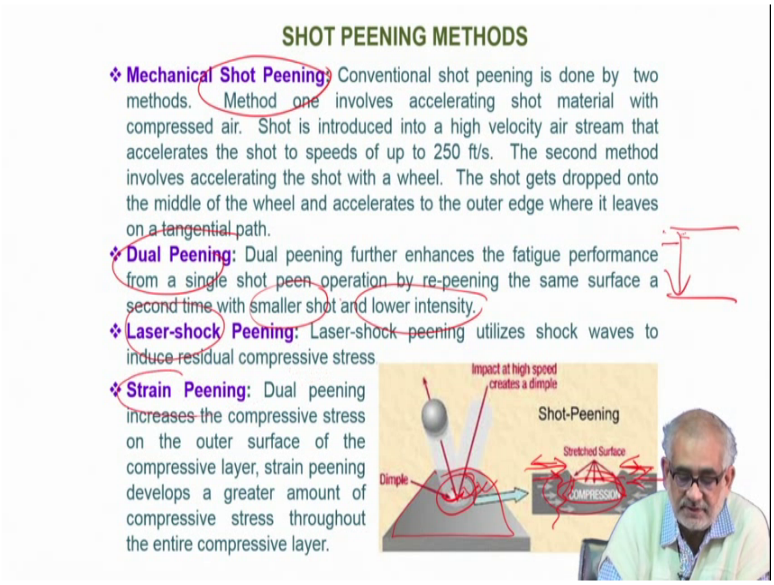

I have already explained that when the impact happens you actually create a small indentation or so, called dimple and there is a little curvature created. And this curvature due to multiple subsequent shots from several other randomly falling objects will essentially create a uniform depth of deformation and uniform area coverage throughout the surface.

The biggest advantage always we should remember is the creation of this state of compressive stress onto the surface where the forces are actually acting towards each other. And hence if at all there is any crack or discontinuity created first this crack has to see a situation where the state of stress is reversed from compressive to tensile and then only this crack can further open.

So, this is kind of a preventive measure created by the state of stress which actually prevents any kind of crack growth particularly under fatigue or such operations. So, you can do a mechanical shot peening you can do dual peening, where you can actually have peening. Initially with a particular size followed by another size maybe a smaller shot with lower intensity.

So, actually if this is the depth of the deformed zone then actually the state of stress that you create can vary. So, it actually everything is a negative, but the amplitude will be lower or higher along the depth. So, as a result you can have a graded state of stress towards the surface. Instead of mechanical impact you can use a laser assisted shockwave which can create such state of residue a state of compressive stress on the surface you can also do strain peening by using other kinds of a impacting objects.

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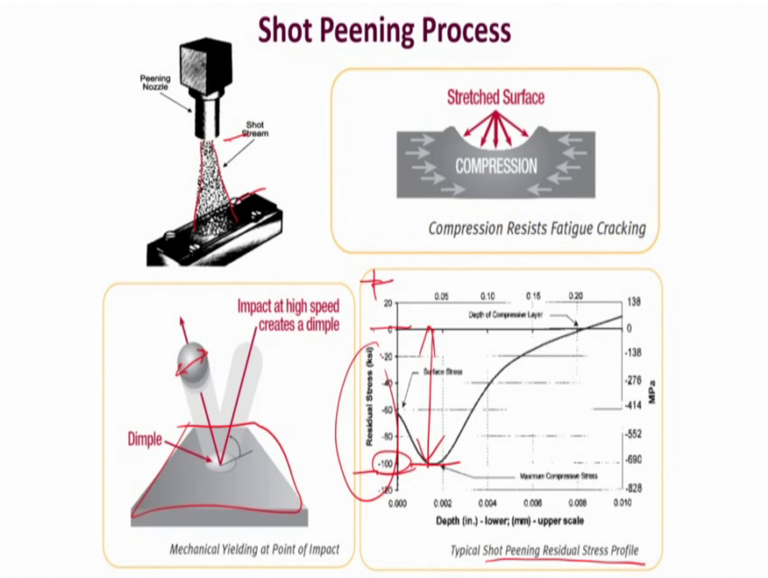

So, this is sort of an idea as to how small these shots are compared to the overall surface that we are trying to treat. So, in this cartoon you cannot make out the size difference, but imagine this is less than a millimeter maybe 0.3 0.4 millimeter and this surface area can easily be a meter by meter or half a meter by half a meter.

So; obviously, you require a gun which actually will be throwing these projectiles and the projection will be little divergent, but depending on this distance and the velocity with which they are coming the size and the weight and the material of these shots the state of the condition on to the surface.

The angle of incidence all these parameters will determine what will be the state of stress now. So, this is the neutral plane and this is the tensile side and this is the compression side. So, by way of introducing such shot peening you actually always create a residual stress which is compressive in nature and this actually can be fairly large for example, the total at certain depth below the surface you actually can have fairly large amplitude large magnitude of residual stress created.

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Factors influencing the fatigue property

	Step	Promotive parameter	Resistance parameter		
			Yield stress (Vickers hardness)	Grain size	Compressive residual stress
Stage I crack	(1)	Shear stress	◎	◎	×
	(2)	〃	◎	◎	×
	(3)	〃	◎	◎	×
	(4)	〃	×	◎	◎
Stage II crack	(5)	Tensile stress	×	×	◎
	(6)	〃	×	×	◎
	(7)	〃	×	×	◎

◎:contribute considerably, ×: have no relation

Coverage: Area fraction of the component surface impacted in a given peening time representing a degree of interaction between neighboring indentations, and hence the uniformity of residual stress on the surface. It is expressed as (Avrami equation):

$$C(t) = 100\left\{1 - \exp\left(-\frac{3r^2\dot{m}t}{4A\bar{r}^3\rho}\right)\right\}$$

where ***r*** is the average radius of indentations, ***A*** is the area of shot spread, ***t*** is the cumulative time for impact or indentations, ***m*** is the mass flow rate, ***p*** is the density, and ***r*** is the average radius of the shots

So, there are actually various factors which influence the residual stress development on to the surface. The most important thing that we have to realize that if you are talking about a large surface area and each of the short is only this small, then you actually need quite a bit of a the entire operation should have a fair amount of overlapping otherwise you cannot create an uniform state of stress throughout. And this kind of a possibility is can be actually modeled through typically an average equation which is a function of the size and the velocity and also the speed at which they are covering the entire surface integration for the entire surface.

So, parameters that we need to actually take into account at the mass and the rate at which the mass is impacting the surface the density, the radius of the shots; obviously, the area that is spread under the deformed zone and certainly the time for cumulative time for this entire process.

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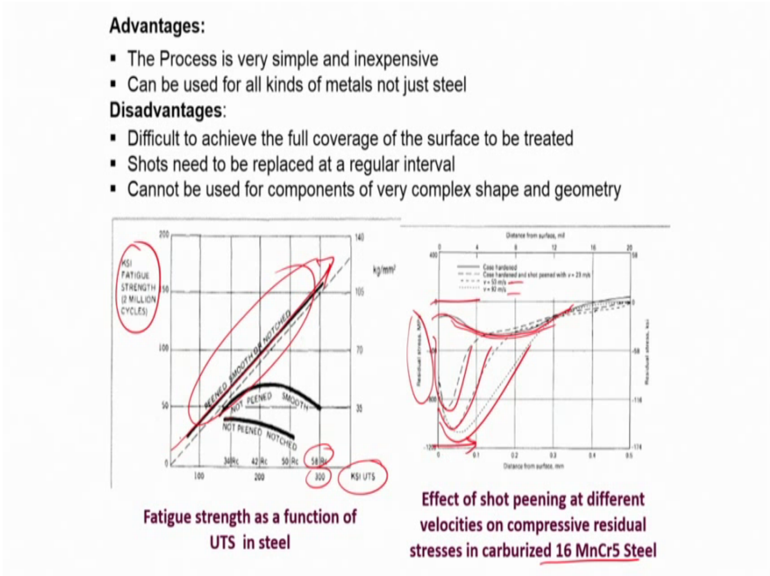

So, imagine, so, this is the fatigue strength of a particular material against the UTS of that particular material. Now a when you when you compare different kinds of conditions. So, this is the condition of the of the particular steel without shot peening this is with this is also without shot peening but this is with the definite amount of shot peening.

So; that means, after the shot peening operation what we see is that the fatigue strength of the material is uniformly increasing as the key as the UTS of the material is going up. Or in other words at higher and higher level of UTS or higher level of hardness level we will actually see after shot peening that the fatigue strength of the material uniformly increases. So, that certainly is very very beneficial for all kinds of rotating components. In fact, for a given steel which is carburized steel now normally we will we have not discussed as yet, but carburizing treatment followed by a certain surface thermal treatment develops predominantly martensitic microstructure.

And when we develop martensitic microstructure then we believe we actually may expect that the state of stress onto the surface is residual compressive in nature, but what its shown here is that for a carburized steel this is the neutral plane so; obviously, this is in the compression zone. So, the residual stress is compressive in nature, but when you actually follow the carburizing and heat treatment with follow it up with a shot peening then the state of stress can be actually much low much higher.

In magnitude in the negative direction meaning the magnitude of residual stress is much higher if you follow up carburizing with shot peening. So, at higher and higher level of a peening velocity you develop actually much higher residual stress, but what is more even more important is that the state of stress actually is confined to very shallow depth romped from the surface.

So, you leave most of the bulk unaffected only thus near surface region is affected which can be just about a 100 a micrometer or less. There are typical advantages for example, this process I told you at the very beginning that we can consider shot peening to be one of the conventional practices, but it does it is being used for you know more than 100 years, but that is simply because the process is very simple and inexpensive.

And can be easily applied you do not need a very high level of skill set for applying this shot peening and it can be the most important things is it can be used on all kinds of metals not just steel for example, non ferrous metals or cast iron or various kinds of metallic coatings and welded joints and so on and so forth. But usually confined to metals because you do require a certain deformation plastic deformation, generation of dislocations, higher dislocation density which is what will be responsible for creation of residual compressive stress. For example, if you are on the other hand if you are talking about silicate glass or a nitrides or carbides or borides or boride coated components.

Its very difficult to imagine that shot peening will create residual compressive stress onto the surface because there is no surface deformation possible by way of impacting with this steel shots. But there are certain disadvantages always. For example, if you are talking about a large surface area, then to cover the entire surface area and make exactly uniform state of stress requires quite a bit of a trial and various kinds of experimentation. And there will be always certain level of variations at some micron level. Also we believe that the shots we expect the shots should always remain geometrically spherical and maintain the same level of hardness.

But these ones are supposed to be very rigid, but if you are dealing with steel shots or even you can use carbide shots or some other ceramic materials, but they do get deformed after a while. So, instead of complete spherical if this becomes oblate or such kind of a non spherical shape then; obviously, the shot can hit either in a flat condition like this or in a perpendicular condition like this. So, as a result your entire Hertzian distribution of impact is going to be affected.

So, whatever you have calibrated you may not derive the same effect. So, in that case a we need to make sure that the shots should actually remain spherical and just to ensure that what you should do is depending on the material that you are treating beyond a certain period you should change the shots time to time or introduce fresh lot of shots.

So, we need certain changes at regular intervals and also if you have really very complex shape and geometry now normally because the short size is very small as I said much less than a millimeter maybe less than even half a millimeter. So, even at the root of a weld you can a expect shots to cover, but if you have really very complex shape and also crevices like this then its very difficult to go all the way down.

So, for example, if you are a dealing with a with a ball bearing and the bearing is very complex where the route is very very narrow and very deep below then there will be difficulty in reaching up to the bottom of the; bottom of the the teeth.

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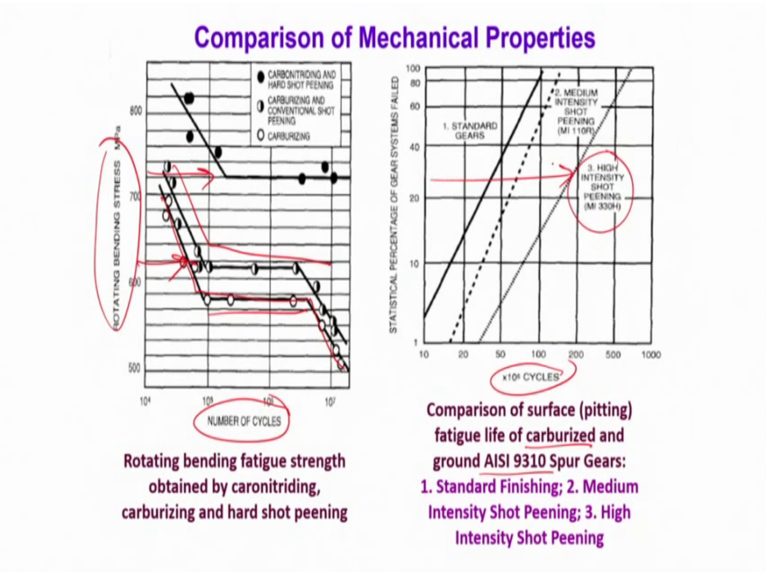

So, again here is a nice comparison that this is. So, this is basically the rotating bending stress that you the member experiences and this is a number of cycles. So, when you have a carburized condition of steel this is how the fatigue behavior is expressed. When you actually follow up carburizing with the conventional shot peening then the situation is improved. So, you have slightly higher endurance limit, but when you have carbonitriding followed by hard shot peening, then the fatigue life is significantly improved.

So, its not just the surface treatment alone I mean the chemical treatment alone which fetches the result, but combination of the surface chemistry change followed by this mechanical control deformation can actually give you much higher fatigue strength. And this actually is important for all kinds of metallic materials particularly various types of steel. So, here is a carburized steel with on this particular alloy and this is a spur gears and the so, typically the number of cycles required for a failure would be much more when you have high intensity shot peening on the same material.

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Points to ponder (recapitulation):

1. What is a peen and peening?
2. What are the different methods of shot peening? Does the principle mechanism vary in these techniques?
3. What state of residual stress is created on the surface and how?
4. What materials and shapes are suitable for shot peening?
5. What are the typical process parameters of shot peening?
6. Will shot peening be effective for hard ceramics, glass or cross-linked polymers?

So, time to recapitulate first of all we have understood what is a peen which is the rounded or the blunted head side of a hammer and peening means as if you are hitting with such blunted heads. So, when you hit you deform up to a limited depth and this kind of a deformation can create a certain level of accumulation of dislocation creation and accumulation of dislocations which in turn can create a residual compressive stress.

So, and that is that brings in certain beneficial effects as far as fatigue strength or several other mechanical properties are concerned. The mechanism is a more or less same no matter what kind of peening process we are doing whether with shorts or pin needles or with some other agencies wires and so on.

But the so, principle mechanism remains the same. The state of residual compressive stress is created because of the mechanism that I just explained that you deform, you indent the material flows and the reaction to that is to bring the material pull in to the center. So, you create a state of stress which will actually act towards each other.

So, this kind of a state of stress which acts towards each other is the compressive stress and onto the surface when we create that by way of this shot peening we create higher or improve the fatigue strength. Usually metallic materials and alloys which actually are amenable to deformation plastic deformation easily, they are the ones which are suitable for shot peening and not ultra hard or non deformable rigid solids for example, you do not do it for a semiconductor or a carbide or nitride at surface and so on.

The process of the shot peening is throwing of those hard objects onto the surface, plastic deformation, tendency to recover and then creation of the state of stress which is compressive in nature. And this is what we need to understand that, how it varies from material to material so; obviously, you would not throw at the same velocity with the same mass or the same size of the shots to all kinds of metals.

I mean it cannot be a universal velocity size and a type of materials that are used as shots for different kinds of materials to be shot peened.

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So, what actually we learn a final take away from this discussion, so far is that even though it is a conventional process, but shot peening is still a very widely practiced economical and very very effective means of creating residual compressive stress on flat or curved surfaces even with complex geometry. So, that we are able to create residual compressive stress and for all rotating members or members which actually experience cyclic stresses, this creates a higher fatigue life for the material.

Thank you very much.